

Remote Sensing and Water Balance Modeling in California Drip-Irrigated Vineyards

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Abstract

Advanced computing technologies are being developed to combine remotely sensed imagery with ancillary data for production of ecological and agricultural “nowcasts” and forecasts. NASA’s Terrestrial Observation & Prediction System (TOPS) uses Earth-viewing satellite imagery to generate data fields related to hydrology, meteorology and ecosystem structure and function over regional to global extent, with products posted to the Internet on a daily-to-weekly basis. During the 2005 growing season, TOPS operated in conjunction with a water balance model and high resolution satellite imagery to generate daily nowcast/forecast maps of crop evapotranspiration (ET), soil moisture (SM), and leaf water potential (LWP) throughout a 400 ha California winegrape vineyard. The prototype was designed to enhance grower understanding of the effects of climate, soil water holding capacity, and crop vigor on such crucial factors as soil moisture, crop water stress, and irrigation demand.

Terrestrial Observation & Prediction System

NASA is developing a distributed computing architecture for the production of ecological nowcasts and forecasts from satellite remote sensing data, ancillary data, and Earth simulation models. Emergence of ecological forecasting as a rigorous, scientific endeavor is enabled by the observing capacity of operational satellites, speed and flexibility of the Internet, and the use of high-performance computing for complex modeling. The Terrestrial Observation & Prediction System (TOPS) is designed to seamlessly integrate data from (satellite, aircraft, ground) sensors with weather/climate forecast and land surface models (e.g., Pierce, 2001) to quickly and reliably produce operational nowcasts and forecasts of ecological conditions (Fig. 1) (Nemani et al., 2003, 2006). By automation of data retrieval, pre-processing, integration, and modeling steps, TOPS maps current (nowcast) and predicted future ecosystem conditions, allowing data products to be used in an operational setting for a variety of applications. The system encapsulates nearly two decades of NASA investment in vegetation remote sensing, land cover mapping, and ecosystem modeling at watershed to continental scale.

An ongoing TOPS implementation, based on NASA/MODIS imagery, automatically generates daily gridded fields of meteorologic, hydrologic, and carbon cycle variables at State (1 km) and Continental (8 km) scale (<http://ecocast.arc.nasa.gov>). Nowcast products include leaf area index (LAI: m² leaf area/m² ground area), fraction of absorbed photosynthetically active radiation, gross and net primary production, soil moisture, max/min temperature, vapor pressure deficit, precipitation, and incident shortwave radiation, snow cover and depth, growing season dynamics (leaf on and leaf off), evapotranspiration and streamflow.

Regional implementation consists of first developing the appropriate parameterization scheme for the area and phenomenon of interest. Given the diversity of available data sources, formats, and spatio-temporal resolutions, system automation is critical for timely, reliable delivery of data products for use in operational decision-making. Inputs can include data on soils, topography and satellite derived vegetation variables. After passing through a specification interface in which each parameter is mapped to a list of attributes (e.g., source, resolution, quality), each data field is self-describing to TOPS component models, such that any number of land surface models can be run without extensive manual intervention (Fig. 2).

TOPS exploits two key software components flexibility and automation - Java™ Distributed Application Framework (JDAF) and IMAGEbot planner (Votava et al., 2004). Using a library of Java wrappers to interface to legacy code contained within multiple Earth science algorithms, JDAF provides flexibility to add new modeling components to TOPS with reduced integration effort. IMAGEbot is a planner-based agent that automatically generates and executes data-flow programs in response to user specified goals. Through these technologies, TOPS can be quickly tailored for various end-users with applications ranging from global long-term scientific monitoring of environmental change to near-real-time analysis of relatively dynamic events such as floods, fires, and droughts.

Water Balance Simulation

During the 2005 growing season, TOPS was coupled with a Kc-based water balance model to produce daily, real-time maps of soil moisture (SM), leaf water potential (LWP) and forecasted irrigation needs for a 400 ha Napa Valley vineyard. The Vineyard Soil Irrigation Model (VSIM) simulates daily water balance as a function of leaf area index, weather, soil texture, soil depth, and rooting depth (Fig. 3). VSIM uses weather and reference ET measurements of the California Irrigation Management Information System (CIMIS, 2005) to simulate current conditions. The user can manipulate LAI, weather, soil water holding capacity, and cover crop to examine effects on soil moisture and vine water stress. Water gains (rainfall, irrigation) and losses (ET, runoff) are used to revise soil moisture and plant stress (leaf water potential) on a daily basis (Figs. 4, 5). The model can apply 7-day forecasts from the National Weather Service, National Digital Forecast Database (NDFD, 2005) to forecast irrigation demand.

NDVI imagery collected during climax LAI during a prior year was combined with growing-degree-day (GDD) summations to evaluate and update the crop coefficient (Kc) throughout the season. Daily LAI was specified for each 4m x 4m model cell based on a normalized curve

(range 0-1) relating LAI to GDD summation beginning at budbreak (Fig 6). Climax LAI associated with the curve peak was obtained by analysis of high-resolution satellite NDVI imagery, converted by ground measurement to LAI as per Johnson et al. (2003). Daily Kc was calculated from LAI, per cell, using Beer's Law and a light extinction coefficient (Ross, 1981). A scalar was automatically applied to reduce Kc in the presence of moderate to severe water stress (beginning at LWP of -5 bars), to simulate the effect of stomatal regulation (e.g. McCarthy et al., 2002; Schultz, 2003).

Within the TOPS environment, an automated Linux script was implemented to transfer data from the external CIMIS and NDFD archives to a local database, execute the water balance model, export binary raster output to an ftp archive, and convert the binary data to Portable Network Graphics format for Internet posting. The Linux *cron* utility was used to schedule the daily sequence of events, and enable polling of the local database for successful data download from the external archives. Under normal circumstances, the external data were accessed and transferred at 7:45 am, the model initiated at 8:30 am, with all output archived and available for viewing by 9:00 am.

Simulation map products posted to the web included LAI, SM, LWP, cumulative applied irrigation, and cumulative water stress (Ecocast, 2005). The system also monitored the date at which a specified target level of water stress was initially reached, signifying the need to commence irrigation. National Weather Service 7-day forecasts were used to specify irrigation recommendations, based on a specified target stress level (leaf water potential) (Fig. 7). Tabular output, keyed to the grower's field boundary database, provided a daily field-level summary of all output variables. Additional rasters showed end-of-season cumulative crop stress and cumulative water application.

Conclusion

The prototype system described here develops agronomic information from disparate data sources including remote sensing, with timely distribution of actionable products to end-users. Water balance simulation adds value to NDVI imagery that is already purchased and used, frequently in qualitative fashion, for a variety of management decisions by California winegrowers and water resource agencies. Upon further evolution into an operational framework, the tool will assist growers in efficient water management and maintenance of prescribed water stress level (a key determinant of fruit quality) throughout their vineyards.

Additional validation efforts are ongoing to better understand dependencies among ETc, SM and LWP by accounting for varietal differences in stomatal regulation, and to further explore the linkage between remotely sensed NDVI and Kc in vineyards. As the simulation capability is further developed and joined with an increasingly rich and accessible body of earth observational data and weather forecasts, it should support improved tactical (grower) and strategic (resource agency) water management in various crops at local-to-regional scales.

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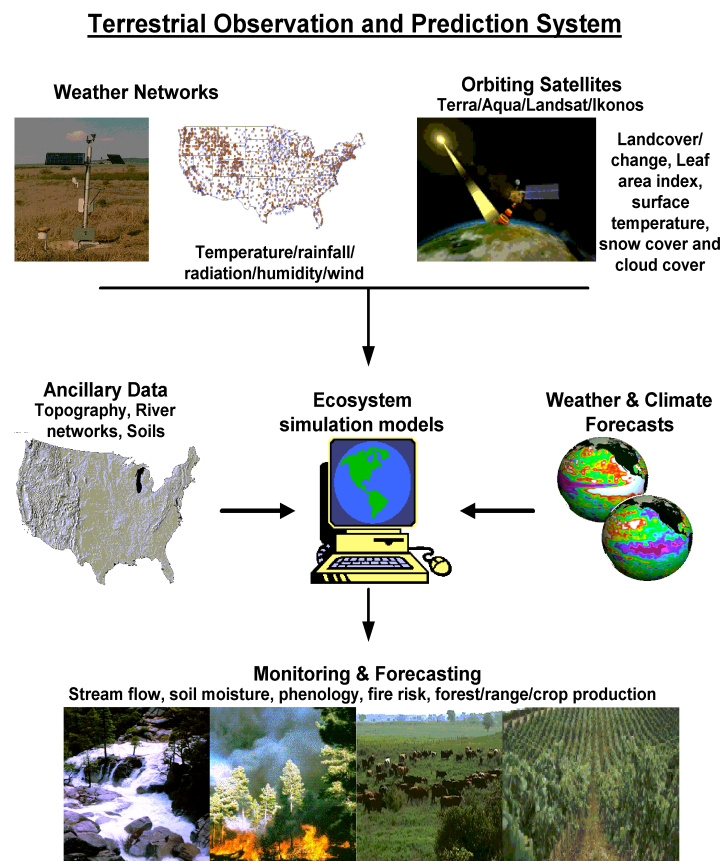


Figure 1. TOPS integrates models and data from several sources to produce operational nowcasts and forecasts of ecosystem variables for natural resource management. The system encapsulates nearly two decades of NASA investment in vegetation remote sensing, land cover mapping, and ecosystem modeling from watershed to continental scale.

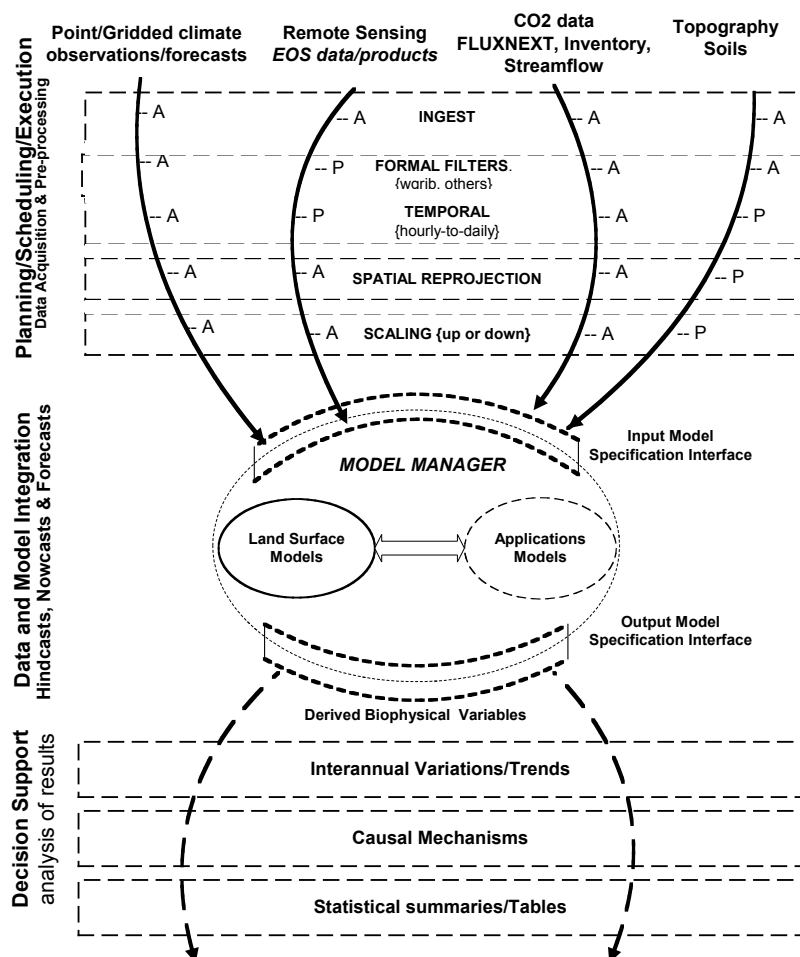


Figure 2. TOPS data processing flowchart. Some of the inputs (top) are acted upon ("A") and others pass through ("P") various processing filters before integration with model(s) for analysis and generation of decision support products (bottom).

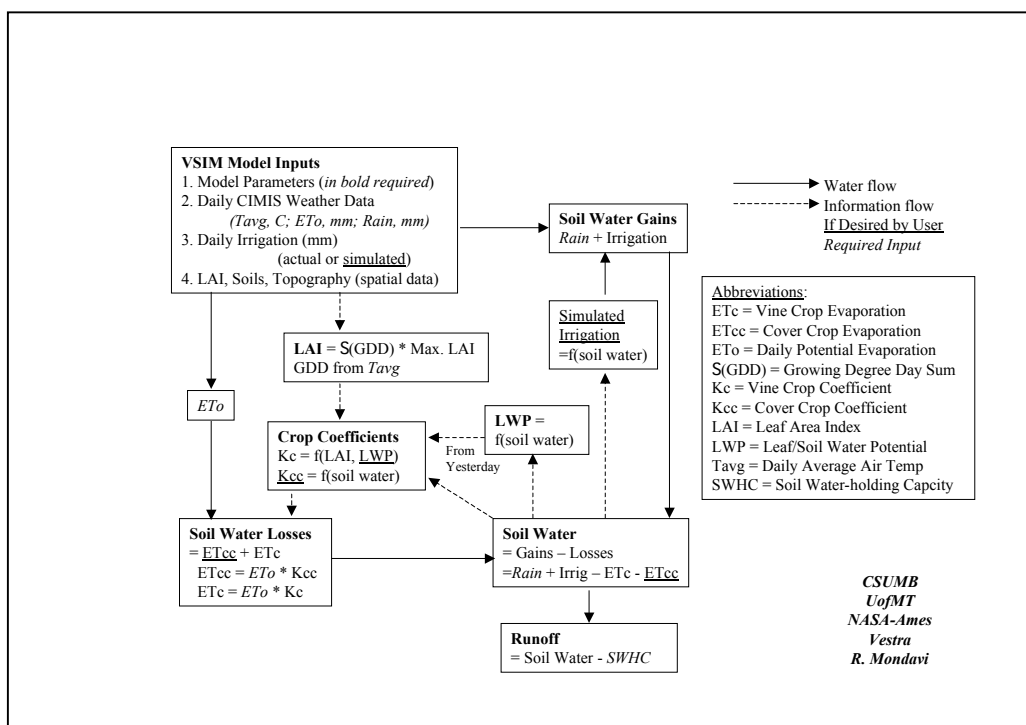


Figure 3. VSIM water balance model, daily process flowchart. Model and user guide available on <http://geo.arc.nasa.gov/sge/vintage/vsim.html> courtesy NASA VINTAGE Project.

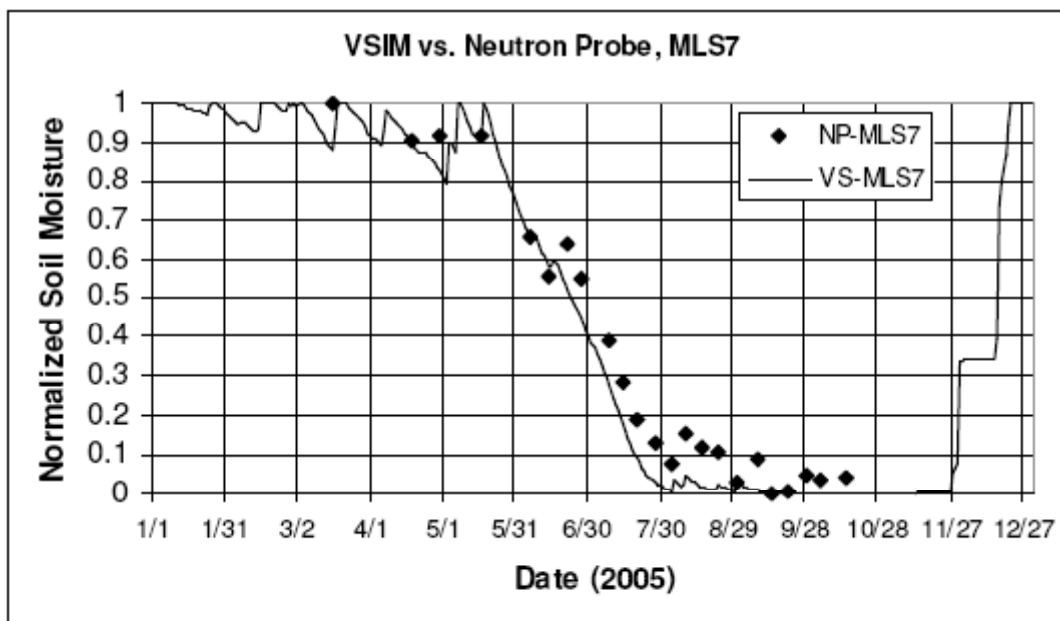


Figure 4. Simulated (continuous line) vs. measured soil moisture, both normalized, for a Cabernet Sauvignon vineyard block, Napa Valley, calendar year 2005.

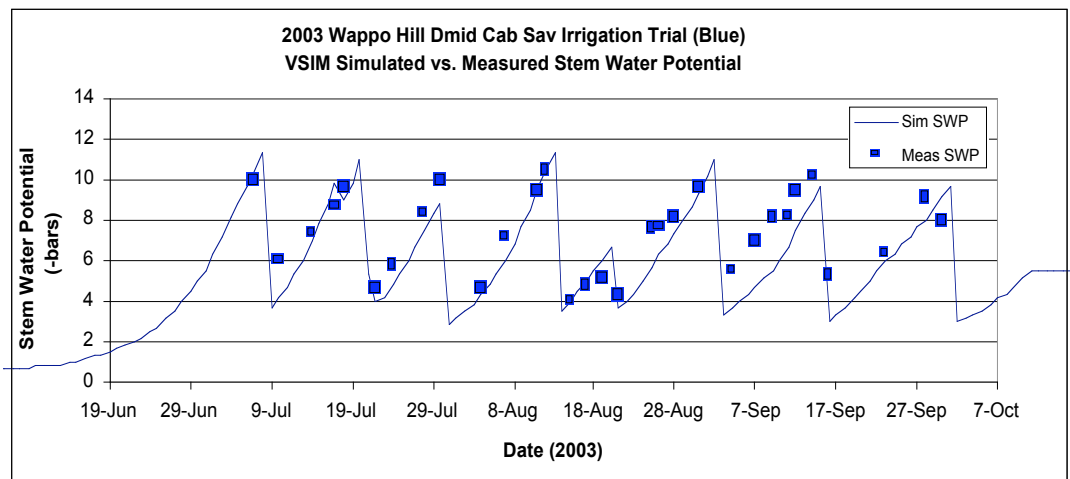


Figure 5: Simulated vs. measured stem water potential for a Cabernet Sauvignon (CS) block in the Stag's Leap District of the Napa Valley, 2003. Approximately 32mm of irrigation was applied every 2 weeks (spikes) to the CS block after the critical water stress was first achieved in mid-July.

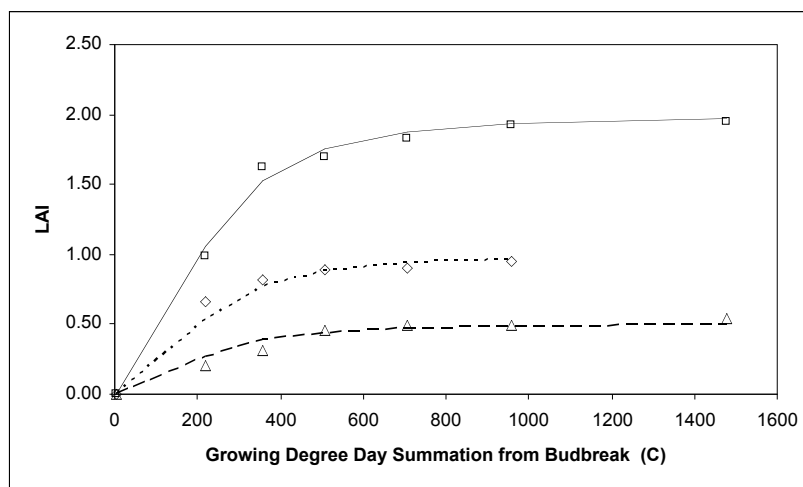


Figure 6. Simulated (line) and measured (symbols) leaf area index by growing degree-day summation from budbreak for three Napa Valley vineyard blocks, 2001 growing season.

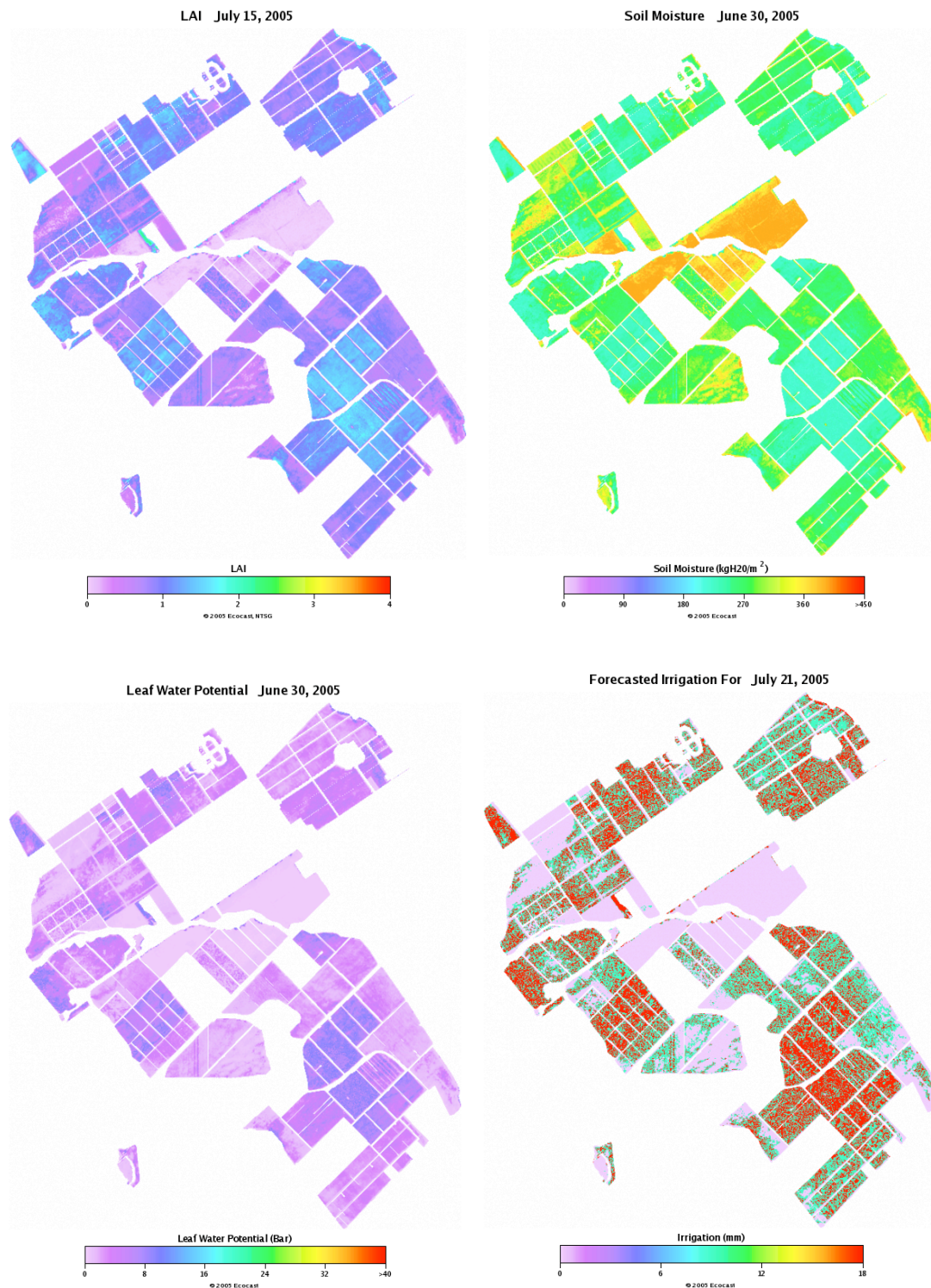


Figure 7. Example daily water balance products for 400 ha Napa Valley vineyard. Images and seasonal animations on <http://ecocast.arc.nasa.gov/images/html/napa/index.html>